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Interoperability in Multi-layered Active Defense:

The need for commonality and robustness
between Active Defense weapon systems

by

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Biography

Lt Col Gil Dolov entered the Israeli Air Force in 1995 where he has served in the air defense array and has many years of combat operational experience. Lt Col Dolov has the proficiency for operating two different defense weapon systems: the Hawk and the Arrow. He served as a Hawk battery commander while deployed to the north part of Israel. Following this assignment he attended the undergraduate program at Tel Aviv University and has a Bachelor of Arts in Computer Science. After his graduation he served as the commander of the Patriot and Hawk Air Defense School and as the Arrow battalion weapon system Executive Officer. He moved to the Israeli Air Force staff as the Air Force Active Defense Training and Doctrine Commander. Following his staff assignments, Lt Col Dolov was assigned as the air defense basic training school commander and then he was nominated to be the commander of the Arrow active defense weapon system battalion. Lt Col Dolov fought and participated in the 2006 second Lebanon War and 2014 Protective Edge war. He was also a participant in the 2011 and 2013 combat operations Cast Lead and Pillar of Defense, respectively. Lt Col Dolov is currently a student at the Air War College at Maxwell Air Force Base, Alabama.

Abstract

Since World War II nations have increasingly relied on ballistic missiles. The use of ballistic weapons allows the attacker to save resources and reduce the use of air power. Ballistic weapons are cheap, deadly and likely to be used by poorer countries. As technology has enabled the combination of nuclear weapons with ballistic missiles, the influence of these weapons has become much more threatening and strategic. The armament of ballistic weapons has become a worldwide proliferation phenomenon. During the last three decades, the Arab countries, especially those in the Middle East, have begun to obtain ballistic weapons at an increasing rate.

Most Missile Defense operational systems worldwide operate on the same basic principles. It is likely that in the near future collaboration between the active defense systems will be primarily between the United States and countries which are supported by Western alliance missile defense such as Japan, France, Germany, Israel and Italy. These systems operate on the same basic concept. But in practice, each system operates independently. This paper argues that the most efficient concept for integrating active defense weapon systems is a multi-layered architecture with redundant intercept capabilities. Using a robust and universal data protocol for interoperability between different weapon systems in a multi-layered architecture will allow faster data transfer and will prevent data loss. The need for almost 100% interception successes is increasing as the threat becomes more destructive. Using universal and robust data capabilities and universal interfacing between the various weapons systems will ensure victory in future campaigns.

Introduction

Since World War II nations have increasingly relied on ballistic missiles. The use of ballistic weapons allows the attacker to save resources and reduce the use of air power. These weapon systems are cheap, deadly and likely to be used by poorer countries. Furthermore, ballistic missiles are constantly being improved.¹ In World War II the Germans bombed the United Kingdom with thousands of ballistic missiles, yet this threat did not change the face of the war nor tip the balance in favor of Germany.² However, over the years by combining nuclear weapons and ballistic missiles, the influence of ballistic weapons has become much more threatening and strategic.³

The armament of ballistic weapons has become a worldwide proliferation phenomenon. During the last three decades the Arab countries, especially those in the Middle East, have begun to obtain ballistic weapons at an increasing rate. In 1998, a study published by Congressional Committees, stated that approximately 25-30 countries were seeking to develop non-conventional ballistic weapons.⁴ In 2006, more than one hundred ballistic missiles were launched around the world as part of ballistic missile firing tests.⁵ The increase of ballistic missiles and rocket tests rises each year by 10 percent.⁶ Today, all the countries which have a nuclear capability also have the ability to launch medium- and long-range ballistic missiles. In 2004, a report by the head of the International Atomic Energy Agency (IAEA) declared that over 40 countries have the capacity to produce nuclear weapons.⁷ As of 2009, the total ballistic missiles in the world not including the manufacturing countries such as the United States, Soviet Union and China stood at over 5,900 missiles. For example, in the Middle East, Syria has hundreds of ballistic missiles, especially large surface-to-surface missiles which are now mainly used against rebel forces.⁸

The use of non-accurate ballistic missiles does not allow a strategic change in the development of the campaign. For example, during the first Gulf War when 19 inaccurate Al-Hussein missiles with a Circular Error Probability (CEP)⁹ of 3,000 to 4,000 feet were launched toward Israel, they caused relatively little damage. No Israeli was killed by a hit from an Al-Hussein missile. During that war, dozens of Scud missiles were launched toward Saudi Arabia and one of them hit a non-protected building in a US military base and killed 28 American soldiers. However, the overall damage caused by Iraqi missile attacks on Israel and Saudi Arabia was negligible. If the shooting towards Israel was intended to force Israel to intervene in the war to dismantle the coalition against Iraq, then that goal was not achieved. If the shooting against Saudi Arabia was designed to disrupt the Allied operation, this goal was not achieved.¹⁰ However, a hit on a site or facility which contains dangerous substances may increase the damage and effect on the battlefield. An accurate ballistic missile has far-reaching military significance threatening facilities such as airports and emergency stores or power plants. Thus, the need for the active defense weapon systems is important and required to achieve almost 100% efficiency.

For achieving maximum efficiency against the ballistic missile threat, a combination of several defense weapon systems, which are operating in different layers, has to be established. In most cases, this kind of multi-layered architecture will be based on various types of weapon systems, which can be operated by different countries. In order to achieve the maximum robust efficiency between all the weapon systems in the architecture, **a full interoperability and common language is required** in order to allow an integrated sky picture¹¹ that will be the base for a central management interceptions center. The differences between the active defense weapon systems nowadays are obstacles in effectively connecting all the weapon systems and

establishing a unified sky picture. Moreover, it weakens the ability to manage interceptions in a centralized method. **A definition of universal common language and communication between the active defense weapon systems in a multi-layered architecture**, will establish a robust and powerful defense by maximizing the effectiveness of a multi-layered defense weapon systems.¹²

In this paper, I will present the ballistic missile defense systems race against the ballistic missile improvements and proliferation and will analyze the need for robust and communal defense weapon systems. Today, in the face of strategic threats and the use of unconventional weapons, active defense weapon systems are required to achieve almost 100% efficiency. To provide such effectiveness, the active defense weapon systems are required to cooperate and create a multi-layered array that will serve as a powerful unified architecture. I will present the different types of ballistic weapon system and the complexities of operating this system in the battlefield. I will elaborate on the multi-layered architecture concept and finally I will explain the need for commonality and robust defense weapon systems and its advantages.¹³

Definitions and Active Defense System Types

There are four categories for classifying defense weapons against the ballistic threat. The first category is the stage for intercepting the ballistic threat. Second, there is the interceptor location (air, sea, land). The third category is the killing mechanism type for the destruction of ballistic missile and fourth, there is the type and the location of the sensor which detects the ballistic weapons.

The interception location category

The first category deals with where the threat is being intercepted and is divided into four sections. The first section is intercepting the threat while it was still on ground (before launch). At this point the weapon is very vulnerable unless it is being stored in a silo or carried by submarines. The next three sections are related to the flying phase of the ballistic weapon – the boost phase, the mid-course phase and the reentry into the atmosphere which is the terminal phase.¹⁴ The boost phase is relatively very short and therefore any attempt to intercept the ballistic missile requires the interceptor to be very close to the launch site. At this point the ability to discover the launch by a ground remote sensor is nearly impossible. The ability to discover the boost phase can be done only by satellites which do not provide enough accuracy. The mid-course is the longest stage to detect and intercept the target by a calculation of its predicted ballistic trajectory as long as the target is not maneuvering or changing its speed or direction. In order to intercept the ballistic missile at the mid-course phase the active defense weapon systems have to be very energetic, first to be able to detect the target from a far distance and second to be able to discriminate and intercept the target in high altitudes (usually in space). Furthermore, at the mid-course phase it is highly difficult to distinguish (discriminate) between the warhead (Reentry Vehicle - RV), the booster and other debris of separation due to movement

in space. The terminal stage of the ballistic missile course is the reentry phase into the atmosphere. At this stage the ballistic missile speed is extremely high (3,000-4,000 m/s) and growing. Moreover, at the reentry phase, due to the air friction, additional disintegration phenomenon occurs and more bodies are being detected in the target cluster. There is an advantage at the reentry phase for discriminating the RV due to the different behavior of the bodies in the cluster in high density air. However this advantage comes at the expense of a possible low altitude interception.¹⁵

The interceptor position category

The second category for classifying defense systems deals with the interceptor position (pre-launch) and distinguishes between three types – land, air and sea. The most intuitive interceptor deployment location, in which most of the weapon systems are using, is near the threatened area. These ground interceptor systems such as Terminal High Altitude Area Defense (THAAD)¹⁶ and Arrow¹⁷ have the ability to intercept the target at the mid-course phase and at the terminal phase. Air-based interceptor platforms are usually used for intercepting targets at the boost phase. The aerial platform allows for staying near the launch site and intercepting the target at its boost phase. Nevertheless, this method compels the air platform to fly into the enemy's territory and exposes it to high vulnerability. Sea-based interceptor platforms are similar in concept to ground-based interceptor platforms but add an important flexibility factor for the deployment location and time. However, it does limit the deployment into areas where there is no access to maritime platforms. Sea-based interceptor platforms have the ability to intercept targets at each stage of the ballistic missile trajectory from the boost phase through the mid-course until the terminal phase, depending on the location of the sea-based interceptor platform in relation to the ballistic missile trajectory. The use of sea-based interceptor platforms for

intercepting at the boost phase requires highly energetic interceptors which are capable of accelerating up to 30 Gs, in order to reach the ballistic missile. Examples of this type of interceptors are the Standard Missile 2 (SM2) and SM3 missile, which are launched from an Aegis¹⁸ type ship.¹⁹

The kill mechanism category

The third type of defense system deals with the kill mechanism and there are two main varieties: interception by explosion near the target or direct hit at the target using kinetic energy (Hit to Kill) to destroy it. It was previously believed that the attempt to intercept a target by a direct hit was nearly impossible as it is often compared to an attempt to hit a bullet with a bullet. The first developments were made to use an interceptor that exploded near the ballistic missile and included disruptions using an atomic explosion. Today, we know that it is possible to reach a direct hit accurately and that the use of this mechanism is much more efficient. For example, the THAAD weapon system and Patriot PAC 3²⁰ are using this type of mechanism. Another mechanism is an attempt of using a laser beam which will intercept the ballistic missile but this development is on hold at this time due to lack of resources and appropriate technology.²¹

The sensor location category

The fourth category deals with the location of the sensor which detects the ballistic threat. Again, the use of land-based sensors which are located near the protected area is the intuitive concept that is being used by the majority of the weapon systems. The use of fixed maritime sensors (see platform) or a land-based sensor located closer to the ballistic missile launch position has an advantage of early detection of threats. Satellites are an additional sensor to detect a missile launch at its boost phase. Satellites can detect launches around the world and provide the best warning against missiles attack. However the acquisition accuracy of the

satellite is not high and is based solely on the ballistic missile boost phase. Last but not least is the sensor which is located on the interceptor itself enabling it to identify the target at the end of its flight for a direct hit at the ballistic missile. Nowadays, the basic concept for ballistic missile detection and tracking is based on the initial detection by satellite, tracking the target by land or maritime sensors which are guiding the interceptor with high precision toward the ballistic missile and in the final stage the interceptor uses its internal sensor for hitting the target directly (hit to kill).²²

The Active Defense world complexity

After introducing the various methods of the active defense weapon systems, we will focus on the complexity and the challenges of these systems. Most Missile Defense operational systems worldwide operate on the same basic principles as described above.²³ This list includes the Western systems such as Patriot PAC 3, Arrow, THAAD, Aegis ships with SM3 missiles and also the eastern systems such as A-135²⁴ and the S300VM.²⁵ It is likely that in the near future collaborations between the active defense systems will be primarily between the United States and countries which are supported by Western alliance missile defense such as Japan, France, Germany, Israel and Italy.²⁶ These operational systems mostly operate on the same concept. But in practice, **each system operates independently**, especially for interceptions management. Only some of these weapon systems are using data sharing and external cueing to improve their performance. For example, the THAAD radar is used for cueing and guiding the Aegis SM3 interceptor.²⁷

For the foreseeable future the development and updating of the active defense weapon systems will continue and the current operational systems will be in service at least for the next decade. The US air defense systems such as Patriot PAC 3, THAAD and the SM3 missiles are

mature weapon systems as are the Israeli Arrow, David Sling²⁸ and the Iron Dome²⁹ weapon systems which are all fully operational.³⁰ All of these weapon systems are under constant development. For example, the Patriot Pac 3 will soon use a more advanced interceptor and the Arrow 3 weapon system is on the verge of being fully operational capable to intercept targets at the mid-course phase and so on.³¹ Moreover, there are new weapon systems that are under development and eventually active defense weapon system architecture will include many different weapon systems which are working with different methods and different concepts.³²

The Active Defense Weapon systems efficiency factors

Many variables affect the active defense weapon systems efficiency, to include the interceptor flight time, the ballistic missile type, the size of the protected area. The numbers of targets to intercept per salvo and the weapon system capacity (sensor and interception resources) is a significant factor of the system's efficiency.³³ Today, most of the active defense weapon systems have a very good Probability of Kill (PK)³⁴ (according to firing tests) for intercepting a single target. However, the efficiency of all active defense weapon systems is dramatically reduced when trying to face large salvos especially simultaneously from different arenas.³⁵ In order to face large salvos from different arenas the active defense systems are required to cooperate and integrate in order to have high efficiency for protecting designated regions or countries. The most efficient concept for integrating several active defense weapon systems is based **on a multi-layered architecture** which means that for each target there is more than one weapon system capable of intercepting the target.³⁶ In order to improve the efficiency of the weapons systems in the architecture, the weapon systems have to combine and integrate their sky picture from all the sensors in the architecture.³⁷ In this way the numbers of targets to be processed simultaneously by each sensor is significantly reduced and the ability to discriminate

bodies in each cluster is improved. Additionally, a centralized interceptions management capability will improve the efficiency of all the weapons systems in the architecture by regulating interception resources in such a way that not all the systems will have to intercept all the targets.³⁸

The multi-layered architecture magnitude

Facing a threat of numerous simultaneous targets, a multi-layered architecture of 2-3 weapon systems may provide an appropriate response, but when it is required to face three dozen or more simultaneous targets, a multi-layered architecture built with 5-7 different weapon systems that have different interception capabilities is needed.³⁹ This architecture can be structured by a variety of active defense weapon systems to include land, sea and even air platforms. An example of this kind of architecture may include an Unmanned Aerial Vehicle (UAV) which intercepts targets at the boost phase, an Aegis ship engaging targets using SM3s in the mid-course, a THAAD engaging at the terminal phase with Arrow 2 as backup. At the lower tier, the Patriot and the Davis Sling weapon systems will engage short range targets and cover upper tier weapon systems failures. All of these systems will be connected to different sea and land-based sensors and will be using satellites for cueing.⁴⁰ There are many challenges in operating a multi-layered architecture of such magnitude in both interoperability and with the human in the loop. The challenges will be presented first for a single weapon system and then for interoperated weapon systems in a multi-layered architecture.

The Main Challenges

As noted, the key challenges that the active defense weapon systems is facing for intercepting large salvos is divided into three major issues. First, there is the difficulty in performing a true sky picture analysis from different sensors. Second, there is the challenge of

managing the sensor and interception resources.⁴¹ Third, there is the need to provide more tools for the operators in order to reduce the decision making processes (the ‘human in the loop’ factor).⁴² These challenges are escalated when connecting a number of different weapon systems in a multi-layered architecture.

The ballistics sky picture challenge

Even for facing a single, medium or long-range ballistic missile salvo, the sky picture can be very challenging. Apart from the fact that the active defense sensors are required to discriminate between the booster and the RV after separation, the weapon systems sensors are also required to discriminate, for each ballistic missile, the separation debris which is formed as a cluster around the RV (note: each ballistic missile can have more than dozens of bodies with it in space).⁴³ The weapon systems are required to identify the right body to intercept which is the RV. When facing large salvos, the active defense weapon systems must engage an enormous number of bodies in space. This number can reach into the hundreds. Each weapon system uses many radar resources to discriminate the right body in the cluster to intercept. When required to do so simultaneously for multiple targets, the sensor’s ability to detect new targets is blocked. In addition, the discrimination capability is dramatically dropped.⁴⁴ Another challenge in regards to the sky picture is the effect of upper tier weapon systems interception debris which can block the sensor of the lower tier weapon systems in the architecture.⁴⁵ For example, an SM3’s interception debris after intercepting targets during the mid-course phase will block the sensors of the lower tier weapon system like the Patriot. The lower tier weapon systems sky picture can be completely blocked following a large number of interceptions at high-altitude as they generate hundreds or even thousands of new pieces of debris.

The Active defense resources capacity challenge

The active defense weapon systems are required to deal with many bodies in the sky picture and to perform analysis and discrimination for a true ballistic picture. Each active defense weapon system has limited sensor resources and eventually will reach saturation. Each weapon system has its own capacity level but most of the weapon systems have an independent ability of processing only a few hundred bodies simultaneously. The weapon systems interception resources have a threshold for simultaneous interceptions depending on the amount of available interceptors, the interceptor performance envelope and the fire control capacity for simultaneous interceptions.⁴⁶

The human in the loop factor

The operators are a critical component for managing the weapon system resources both in the sky picture and interceptions management resources. Automations without a human in the loop will waste system resources and can become a weak point for implementing the defense policy. The main operator challenge is to have a proper understanding of the ballistic sky picture by regulating the right sensor resources and controlling the interception resources. Usually, the operator does not have a significant challenge to operate a single active defense weapon system even when facing many targets. But the challenge intensifies when the operator is required to operate, control and coordinate between different weapon systems in the same multi-layered architecture.⁴⁷

Interoperability – A tip of the iceberg

The challenges of the ballistic missile defense have new complexities when it comes to dealing with a unified array of multi-layered architecture. As shown, the effectiveness of multi-layered architecture will be effective only if the active defense weapon systems will share data

and have joint interception management. Without interoperability between the defense weapon systems, each weapon system will operate independently and very quickly will become saturated. Each weapon system will interrupt the other weapon systems interceptions and the interception resources will be used non-effectively. Interoperability between weapon systems in the architecture is a necessity but also brings new challenges. The attempt to correlate and integrate the sky picture in the architecture is a substantial challenge, mainly due to the fact that each weapon system may classify and discriminate the bodies in the sky differently. Each weapon system has its own different communication language and manages differently its own interceptions from a different Battle Management Center (BMC) according to an autonomous decision making process. Weapon systems will classify the sky picture differently, creating an additional resource usage for all weapon systems in an attempt to understand the true sky picture. The numbers of targets that will appear in the whole architecture will possibly be greater than the number of targets in reality due to the inability to correlate between the different sky picture from each weapon system. Likewise, when different weapon systems classify a target differently, there may be a lack of congruence between the two weapon systems. This can cause a process of intercepting a single target by two different weapon systems in contrast to the designated defense policy.

With this in mind, connectivity and interoperability between active defense weapon systems is a necessity. In the future battlefield, the active defense weapon systems will not fight independently. In one way or another, interoperability and information sharing is required in the active defense battlefield.

Levels of Interoperability

Interoperability between the active defense weapon systems is divided into three main levels - voice connectivity, sky picture and data sharing and combined interceptions management. The voice connectivity is the basic level of data sharing and least effective for connecting the active defense weapon systems. It allows data over voice dialogue and provides basic interceptions coordination but hardly improves the capacity of the weapons systems. This kind of communication slightly improves the resources for interception management data sharing and coordination among weapon systems. Using only voice dialogue increases the human in the loop challenge significantly and reduces the efficiency of the operator in the active defense battlefield.⁴⁸ Sky picture interoperability is a significant improvement to a multi-tiered architecture. This kind of interoperability has several advantages. First, it distributes sensor resources between different tasks such as detection of new targets and discrimination (classification) of the current target. Second, it increases the ability to detect simultaneously more targets.⁴⁹ This level of interoperability allows the operator to have a more effective dialogue between the weapon systems. The sky picture is correlated and each weapon system has the same sky picture like all the other weapons systems in the architecture; "everyone sees what everyone sees". The third and highest level of interoperability is a combination of correlated sky picture with the ability to have a coordinated interceptions management.⁵⁰ The nexus for this kind of interoperability is a centralized interceptions battle management center which uses the coordinated and integrated ballistic sky picture based on the generated sky picture by each one of the sensors in the architecture.⁵¹

Today's Interoperability

The majority of western active defense weapon systems can communicate with one another based on Link-16⁵² data communication protocol. This protocol allows effective data communication with a large number of weapons systems including sky picture and interception management message transportation. This protocol can share the capability and performance of each weapon system in the architecture for any threatening target. Some of the weapon systems in the architecture can intercept targets based on this communication protocol using other weapon systems sensors.⁵³ However, there are other communication protocols that exist between western and eastern active defense weapon systems. Furthermore, other communications protocol are available for interoperability between active defense weapon systems, therefore using one communal communication protocol is not intuitive and raises more challenges for adjusting the weapon systems inner data language to be a part of a robust protocol.

Recommendations

Using a robust universal data protocol for interoperability between different weapon systems will allow faster data transfer time and will prevent data loss. There are many existing examples worldwide that exercise a universal language or protocol. These methods rise from the need of connecting different systems in fast and easy ways. One of the best examples is in the world of cellular phones. Mobile companies have decided on a unified communications protocol that allows movement of the mobile phones in the world without having changes in settings or language. For example, the Universal Mobile Telecommunications System (UMTS) is a third generation system for mobile cellular networks based on the Global System for Mobiles (GSM) standard. Developed and maintained by the 3GPP (3rd Generation Partnership Project), UMTS is a component of the International Telecommunications Union.⁵⁴ Although there are many cellular

companies and many different companies who manufacture various types of cell phones, the mobile companies ensure that the user will have an easy and simple communication experience. Consequently, in the active defense world, it is important that the information data for each system will be unified. Although the weapon systems may allow data transfer between each other with a unified protocol, the systems may identify and analyze the ballistic sky picture differently. In that case, messages with the same content may transfer differently causing an error while trying to integrate the sky picture. A unified and integrated ballistic sky picture is critical in the future active defense battlefield when using a centralized interception battle management center.

A centralized interception battle management center in a multi-tiered architecture will allow the best coordinated interceptions and maximize resources management for the best defense capacity of the architecture. A robust universal data protocol will allow a quick connection between the weapons systems. Furthermore, a robust universal data protocol will allow sharing information and interception capabilities and will enable fast interception decisions effectively. This kind of interoperability will allow the human in the loop to receive the best tools and resources for the optimal decision making in reasonable time without the need of using voice. In addition, it will allow the centralized interception battle management center to receive information from all the weapon systems in the architecture about their interception capabilities for each target. On this data basis the operator can choose the best weapon system to use for intercepting a specific target. Furthermore, if one of the weapon systems fails to intercept, a different weapon system in the architecture can intercept the target in reasonable time. Therefore, a centralized interception battle management center has to be able to integrate the various

weapon systems, which requires the use of a universal and robust data configuration protocol for the messages between the weapon systems and the management center.

Conclusion

Today, joint cooperation between countries in the active defense weapon systems arena has the potential to strengthen political ties. Cooperation at different levels and alliances are an important part of the tools in the international community. Cooperation or alliances can be formal or informal with defensive or offensive relationships. Mostly, the broad base of cooperation relies on three main pillars: common interests, shared values and military cooperation. Defense weapon systems development and procurement of defense systems are relatively fertile ground for strengthening the deep ties between countries, for example, the cooperation between Israel and the United States. The joint cooperation is not limited to financial assistance or mutual development, but also in the mutual active defenses. Among the parties, exercises are conducted, which are designed to coordinate the two country's active defense systems. This relationship represents a high level of cooperation, knowledge sharing and a shared vision for future challenges. The countries practice together combined active defense architecture, signaling the combined strength to a future opponent. The Israeli Active Defense array is beyond the narrow dimension of intercepting ballistic missiles and the protection of the Israel. In fact it is a large part of the strategic cooperation with the United States.⁵⁵ The mutual development and mutual practices show that the two countries share their future, both politically and militarily and are willing to share efforts, time and money in joint long-term cooperation. Israel has acquired experience in active defense warfare as a valuable asset for the western bloc countries who have to face the ballistic threat.⁵⁶ A similar cooperation is being held in the Pacific between the United States and Japan,⁵⁷ but in contrast to the cooperation with Israel, both

countries benefit from cooperation with similar weapon systems so the connectivity between the weapon systems of the two countries is simpler. Cooperation in the world has further operational options that link different countries. Certainly, many nations, in the foreseeable future battlefield will use a wider cooperation against common threats. The cooperation may take place between American defense systems, Israel and even European systems. Architecture of this kind can be established for regions such as Europe to protect against the missile threat from Iran. This architecture can be constructed by many participants like the Israeli Arrow, the US Aegis ships and the THAAD system as well as the European ASTER.⁵⁸ All these weapon systems are required to share data and to fight in one coordinated control center in order to maximize the defense capabilities against a strategic threat. Only robust unified data communications interoperability architecture will improve the existence of this type of architecture.⁵⁹

The active defense battle field is unique and challenging with groundbreaking systems and technologies. The need for almost 100% interception successes is increasing as the threat becomes more dangerous and strategic. No active defense weapon system has enough capacity to engage independently all the targets facing large salvos of ballistic missiles in future campaigns. An active defense architecture which combines several weapon systems and shares information is a necessity. Today, the differences between the various defense systems are too big and their ability to connect to one another is complex. **Using universal and robust data capabilities and universal interfacing between the various weapon systems** will ensure victory in future campaigns. It is important to establish such commonalty today when all the weapon systems are in their advanced stages of development.

Glossary

Active Defense – the name for the world of weapon systems against the ballistic threat.

Boost Phase – the first ballistic missile flight phase, from launch until booster cutoff.

CEP – Circular Error Probability is a measure of a weapon system's precision.

Cluster – the bodies in space that belong to the same missile (RV, debris, Booster).

Discrimination – the act of perceiving differences in characteristics between elements of one cluster in the sky picture.

Hit To Kill – the method of intercepting a ballistic missile by hitting it directly versus a detonation next to it.

Human in the loop – refers to having an operator in the decision making process for implementing the defense policy.

Interoperability – the ability of systems, units or forces to provide services to and accept services from other systems, units or forces and to use the services to exchange data to enable them to operate effectively together.

Mid-Course Phase – the second ballistic missile flight phase, from booster cutoff until reentry into the atmosphere.

Multi-layered Architecture – a set of different active defense weapon systems which defend the same asset or territory.

PK – Probability of Kill (for intercepting the ballistic missile).

RV – Reentry Vehicle, in the Ballistic Missile Defense (BMD) world it refers to the ballistic missile warhead.

Salvo – a simultaneous raid of ballistic missiles.

Sensors – all devices that measure physical objects in the Sky Picture and converts them into signals which can be read by observers or by instruments.

Sky picture –describes the Air Situation Picture (ASP) for detection of objects and the classification, association and maintenance of tracks.

Terminal Phase – the last ballistic missile flight phase, starting when the missile is reentering the atmosphere until it hits the ground.

Tracks – an entity (body) in the Sky Picture that is being managed by a detection sensor.



End notes

¹ Arie Stav, *The Threat of Ballistic Missiles in the Middle East, Active Defense and Counter Measures* (Sussex Academic press, Portland, Oregon USA, 2004), 4.

² Williamson Murray, "Reflections on the Combined Bomber Offensive," (Militär-geschichtliche Mitteilungen 51, 1992), 73-94.

³ Sanford Lakoff, *Strategic Defense in the Nuclear Age*, Paredes Security International, (Westport CT, 2007), 2-3.

⁴ Jacques S. Gansler, *Ballistic Missile Defense, Past and Future*, Center for Technology and National Security Policy (National Defense University, Washington, 2010), 55.

⁵ Ibid.

⁶ Ibid.

⁷ Ibid., 57.

⁸ Ibid.

⁹ Circular Error Probability is a measure of a weapon system's precision.

¹⁰ Haiim Rozenber, *The Truth about the Dangers of Missile Attack*, (Maarahot Volium 437, 2011), 94-99.

¹¹ The "Sky Picture" describes the Air Situation Picture (ASP) for detection of objects and the classification, association and maintenance of tracks.

¹² Ben-Zion Naveh and Azriel Lorber, *Theater of Ballistic Missile Defense*. American Institute of Aeronautics and Astronautics (AIAA) (Virginia, 2001), 147-148.

¹³ Lauren Caston, Robert S. Leonard, Christopher A. Mounten, Chad J. R. Ohlandt, S. Craig Moore, Raymoned E. Conely, Ienn Buchan. *The Future of the US Intercontinental Ballistic Missile Defense* (RAND Cooperation, 2014), 5-6.

¹⁴ The course of the ballistic missile has three phases: the boost phase is from launch until the booster cutoff; the mid-course phase is from the booster cutoff until reentry into the atmosphere; and the terminal phase which starts when the missile is reentering the atmosphere until hitting the ground.

¹⁵ Gansler, *Ballistic Missile Defense, Past and Future*, 11-12.

¹⁶ Terminal High Altitude Area Defense (THAAD), formerly Theater High Altitude Area Defense, is a United States Army ballistic missile defense system designed to shoot down short, medium, and intermediate ballistic missiles in their terminal phase using a hit-to-kill approach.

¹⁷ Arrow weapon system is an Israeli Air Force ballistic missile defense system designed to shoot down short, medium, and intermediate ballistic missiles in their terminal phase.

¹⁸ Aegis destroyer guided missile cruisers, a class of warships in the United States Navy.

¹⁹ Gansler, *Ballistic Missile Defense*, 13-21.

²⁰ Patriot is a surface-to-air missile (SAM) system, the primary of its kind used by the United States Army and several allied nations. The PAC-3 missile is dedicated almost entirely to the ballistic missile defense mission.

²¹ Gansler, *Ballistic Missile Defense*, 22-27.

²² Ibid., 28-32.

²³ Naveh and Lorber, *Theater of Ballistic Missile Defense*, 99-107.

²⁴ The A-135 is a Russian anti-ballistic missile system deployed around Moscow to counter enemy missiles targeting the city or its surrounding areas.

²⁵ The S300VM is a Russian anti-ballistic missile system. The system is designed to defeat short- and medium-range ballistic missiles, aeroballistics and cruise missiles, fixed-wing aircraft, as well as loitering ECM platforms and precision-guided munitions.

²⁶ Naveh and Lorber, *Theater of Ballistic Missile Defense*, 147-148.

²⁷ Ibid., 183.

²⁸ The David Sling is an Israel Defense Forces military system, designed to intercept medium- to long-range rockets and cruise missiles, fired at ranges from 40 km (24.85 miles) to 300 km.

²⁹ The Iron Dome is Israeli an air defense system designed to intercept and destroy short-range rockets and artillery fired from distances of 4 kilometers (2.5 mi) to 70 kilometers (43 mi).

³⁰ Department Of Defense, *Ballistic Missile Defense Review Report* (Washington DC, 2010), iii – vii.

³¹ The official Israel DOD site <http://www.mod.gov.il/Defence-and-Security/articles/Pages/10.12.15.aspx..>

³² Reuben Steff, *Strategic Thinking, Deterrence and the US Ballistic Missile Defense Project, From Truman to Obama* (Ashgate Publishing Company, Burlington, USA. 2013), 180 – 183.

³³ Naveh and Lorber, *Theater of Ballistic Missile Defense*, 48-55.

³⁴ Probability of Kill – A statistical number between 0-1 that reflects the success of the missile to hit and destroy the target. For example, if a weapon system is expected to destroy a target nine times out of ten with a representative set of ten engagements; one could say that this weapon has a “PK” of 0.9, as if the percentage of success is nine out of ten.

³⁵ Naveh and Lorber, *Theater of Ballistic Missile Defense*, 167 Fig 11.

³⁶ Ibid., 149.

³⁷ Ibid., 152.

³⁸ Ibid., 150.

³⁹ Ibid., 80-85.

⁴⁰ Ibid., 150.

⁴¹ Ibid., 156-157.

⁴² Ibid., 176.

⁴³ Stephen D. Weiner and Sol M. Rocklin: *Discrimination Performance Requirements for Ballistic Missile Defense* (Volume 7. Number 1, 1994) The Lincoln Laboratory Journal, https://www.ll.mit.edu/publications/journal/pdf/vol07_no1/7.1.3.discriminationperformance.pdf.

⁴⁴ Ibid., 73.

⁴⁵ Naveh and Lorber, *Theater of Ballistic Missile Defense*, 166.

⁴⁶ Ibid., 171-172, Fig 14, Fig 15.

⁴⁷ Ibid., 179.

⁴⁸ Ibid., 162.

⁴⁹ Ibid., 162-164.

⁵⁰ Ibid., 165.

⁵¹ Ibid., 166-167.

⁵² The Link 16 Data Protocol is a military tactical data exchange network used by the United States, NATO and other nations. Its specification is part of the family of Tactical Data Links. With Link 16, military aircraft as well as ships and ground forces may exchange their tactical picture in near-real time.

⁵³ Sun Yiming , *Tactical Data Link In Information Warfare* , University of Posts and Telecommunication, 2005-7.

⁵⁴ *Universal Mobile Telecommunications System*, European Telecommunications Standards Institute, 2008.

⁵⁵ Shahar Shuhat and Yniv Fridman, *From Tactic Defense to Complete Air Defense Array*, Between the Polars, Volume 4, (Dado Institute, 2015), 66-81.

⁵⁶ Department Of Defense, *Ballistic Missile Defense Review Report*, 33.

⁵⁷ Ibid., 32.

⁵⁸ The Aster missile series is a family of vertically launched surface-to-air missiles. Aster is manufactured by Eurosam. The missile is designed to intercept and destroy a wide range of air threats, such as supersonic anti-ship cruise missiles at very low altitude (sea-skimming) and fast flying, high performance aircraft or missiles. Aster is primarily operated by France, Italy, and the United Kingdom.

⁵⁹ Lakoff, *Strategic Defense in the Nuclear Age*, 97.

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